Pebble Mine Geohazard and Tailings Dam Embankments Analyses of Dr. T. O'Rourke and Dr. Izzat M. Idriss

(Submitted Summer 2019 During DEIS Public Comment Period)

EXHIBIT A

T.D. O'ROURKE **Geotechnical Consultant**
10 Twin Glens Road, Ithaca, New York 14850
607-272-4029

25 June 2019

TO: **Bristol Bay Reserve Association**
FROM: **Tom O'Rourke**
RE: **Geohazards Affecting the Pebble Mine Complex**

My comments related to geohazards affecting the Pebble Mine Complex are provided as follows:

1. As pointed out by the U.S. Geological Survey [USGS] (2007), Alaska is the most seismically active state in the U.S. The Pebble Mine Project (Project) would involve a very large mining site and transportation facilities, including a deep and expansive mine pit, waste rock piles, tailings storage facilities (TSFs), roadways, pipelines, bridges, port facilities, ore processing units, offices, housing, as well as water and electric distribution and wastewater treatment systems (collectively, the Pebble Mine Complex). By some estimates, the total areal extent of the Project's mine site operations, not including the full Pebble Mine Complex with off-site roads, pipelines, bridges, and port facilities, would cover 19 mi^2.

A project of this scale and magnitude poses material and significant risks and impacts on important natural resource production and viability, as well as transportation facilities and infrastructure (USGS, 2007). The analysis in the Draft Environmental Impact Statement (DEIS) does not use current data or up-to-date commonly accepted evaluation measures. Unless the DEIS is revised substantially to include the investigations and analyses outlined below, it will not provide an adequate basis to evaluate the risk potential of the Project.

Given the Project's seismic risk, mine size and complexity, and potential detrimental effects on the world's largest salmon run, the DEIS needs to provide an up-to-date evaluation of the regional seismicity, including comprehensive probabilistic seismic and deterministic seismic hazard analyses. The seismic hazard analyses reported in the DEIS are based on ground motion maps that are twelve years old (USGS, 2007), do not include recent seismic activity, and do not include the use of the most recent ground motion prediction equations (GMPEs), known as NGA West (2014). Up-to-date seismicity assessments and GMPEs are generally a prerequisite for the seismic risk assessment of projects with an impact similar to that of the Pebble Mine Complex. In my opinion, it is accepted practice to use up-to-date seismicity analyses and GMPEs to evaluate infrastructure projects with broad life safety and environmental risks, including mines. Since 2015-2016, similar projects have converted to using the most recent GMPEs, which are missing from the DEIS.

2. The TSFs involve very large embankments with projected heights reaching 545 ft that will impound approximately 1.295 billion tons of mine tailings, sludge, and water. To put that into context, the Mount Polley tailings dam embankments in British Columbia, which failed in August 2014, reached a height of approximately 130 feet (U.N. Environment GRID Arendal 2017). The Val di Stava Dam collapse in Italy in 1985 involved tailings dam embankments that were only slightly higher than 110 feet (U.N. Environmental GRID Arendal 2017). Issues related to dam height risk are exacerbated in a seismically active region like Alaska. Simulation results reported by Lynker (2019) show that a breach of a large tailings dam consistent with Pebble Mine Complex operations can inundate waterways in excess of 80 mi. downstream and deposit debris in more than 155 mi. of streams that are mapped as salmon habitat.

Because the consequences of failure are so high, with the immediate release of toxic mining chemicals and wastes, seismic embankment deformation analyses need to take account of up-do-date seismicity and GMPEs as well as the most effective models for ground deformation simulation. The seismic embankment deformation analyses in the DEIS do not include seismicity or GMPEs that are up-do-date. In addition, they are based on simplified sliding block models, semi-empirical predictive relationships, and general empirical methods that do not account explicitly for the liquefaction behavior of soil. Soil liquefaction occurs when saturated soil loses its shear strength and stiffness under applied stress, such as earthquake-induced transient ground motion, and behaves as a liquid.

In contrast, the seismic risk assessment of dams operated by the Los Angeles Department of Water and Power is performed by simulating liquefaction-induced soil deformation using models that account explicitly for soil strength and stiffness loss during pore water pressure buildup in response to seismic motion. In some cases, as many as three different models are used. The employment of different models accounts for uncertainty with respect to the actual liquefaction behavior of soil, and allows for comparison of the collective results that, in turn, enhances the engineer's understanding of the deformation process. In my opinion, the use of current seismic data and GMPEs is the commonly accepted professional standard for evaluation of a critical dam.

The simplified methods employed in the DEIS lead to an estimate of embankment crest settlement on the order of 4 ft under Maximum Credible Earthquake (MCE) conditions. These results are used to conclude that the settlement magnitude is not enough to compromise functionality of the filter zones in the proposed tailings dam embankment nor reduce the crest elevation below the maximum allowable water level behind the dam. In my judgement, the DEIS cannot substantiate these conclusions unless it performs adequate modeling using up-to-date seismicity assessments and GMPEs, consistent with those discussed and recommended in this report.

One problem apparently not addressed in the DEIS is that embankment crest settlement leads to transverse cracks in the dam. If this cracking extends below the water level behind the dam, pathways for flow and erosion will exist with the potential to erode through and overtop the dam. In addition to comparing crest settlement with the minimum freeboard, the analyses should also evaluate the reduction in horizontal soil stress parallel to the longitudinal axis of the dam to determine if enough soil stress exists to resist transverse crack formation. This type of analysis cannot be performed with the simplified models used in the DEIS. Without this evaluation and more rigorous seismic hazard and embankment deformation analyses, the DEIS assessment of the proposed tailings dam is not sufficient to assess seismic risk.

3. Soil liquefaction is a major threat to the many transportation systems and collocated infrastructure planned for the Project, including roads, bridges, culverts, port facilities, and pipelines for transporting various materials including gas, diesel, and water. During the 1964 Alaska earthquake there was widespread failure of railroad embankments and bridges founded on liquefiable soils. The most recent 30 November 2018 Anchorage Alaska earthquake provides evidence for embankment failure at Vine Road in Wasilla, Alaska, underlain by organic peat deposits (GEER, 2019).

The Project will involve as many as 86 mi. of gravel surface access roads. It is estimated that, along the roadways, there may be four pipelines that would carry copper concentrate, water, natural gas, and diesel fuel. The roads and pipelines will cross many streams, rivers, and wetlands that are often underlain by liquefiable soils. Many streams and river crossings will be wide enough to require a bridge, which may be used to carry the pipelines. Experience during past earthquakes, including those in Alaska, show that bridges will fail or deform excessively from liquefaction-induced soil movements. Such failure or deformation may also damage the pipelines. Since the pipelines are collocated, the failure of one can undermine and damage the adjacent lines, thus increasing the overall risk of pipeline failure and release of contents. Because these locations are stream, wetland, and river crossings, the loss of toxic contents will enter waterways immediately with direct impact on salmon runs and associated habitat.

Loss of bearing due to liquefaction of underlying soils will result in road embankment settlement and lateral ground deformation. Such deformation will also affect the integrity of pipelines in proximity to the failed road embankment. The DEIS needs to analyze and evaluate adequately the many impacts on natural resources and transportation infrastructure associated with liquefaction.

4. Seismicity is not the only issue that could affect the Project's infrastructure. The high annual rainfall around the area of the proposed Pebble Mine Complex, in combination with steep mountainous slopes and the absence of significant vegetation at higher elevations, increases the risk and frequency of intense storm runoff. The roadways are exposed to these runoff events, which can lead to washouts of culverts at smaller stream crossings and undermining of bridges at larger water bodies. The washout of a culvert will be accompanied by erosion of the roadway and the undermining of pipelines located nearby and parallel to the roadway. The deformation and/or failure of a bridge will also induce damage to pipelines carried by the bridge, with the potential for release of toxic contents directly into salmon runs. The 2019 tailings dam collapse in the Brazilian state of Minas Gerais is an example of what heavy rainfalls can do to mine infrastructure. In that case, heavy rains led to dam failure, releasing significant amounts of toxic mine wastes and mud, contaminating a major stretch of the Paraopeba River, and killing over 100 people.

5. There have been many tailings dam failures worldwide (e.g., U.N. Environment GRID Arendal, 2017 and 2019; Rico et al., 2007). In view of these problems, the DEIS should identify and address tailings dam failures that have occurred worldwide in a discussion on the vulnerability of tailings dams and the major and most common causes of failure. The DEIS should place the proposed Pebble Mine Complex tailings dam embankments and other infrastructure in the proper context of international experience with these projects, and explain why the proposed dam and infrastructure would not be susceptible to similar types of failures. This assessment should include a discussion and evaluation of the residual risks associated with the tailings dam after cessation of mining operations and closure of the impoundment. The risk of a tailings dam failure and the release of toxic mine wastes will continue after termination of mining operations, and this risk should be addressed and quantified in the DEIS.

The significance of tailings dam behavior is broadly recognized in the engineering community. Indeed, the importance of managing and accounting appropriately for mine wastes is a topic receiving special attention from the National Academies of Sciences, Engineering, and Medicine's Committee on Geological and Geotechnical Engineering (COGGE), which is holding a meeting on June 27, 2019 in Washington, DC, to discuss managing mine waste risks, including a session on managing mine tailings. In its description of the topic, COGGE points out that impoundments containing mining wastes and other particulate materials placed by hydraulic sluicing fail at ten times the frequency of modern engineered dams.

If you have any questions or seek additional clarification regarding my review comments, please contact me directly.

Sincerely,

T. D. O'Rourke

T. D. O'Rourke

References:

Geotechnical Extreme Events Reconnaissance Association [GEER] (2019), "Geotechnical Engineering Reconnaissance of the 30 November 2018 M 7.0 Anchorage, Alaska Earthquake", Eds. K.W. Franke and R.D. Koehler, *GEER-059*, 2 January, 2019.

Lynker Technologies, LLC (2019), "A Model Analysis of Flow and Deposition from a Tailings Dam at the Proposed Pebble Mine", *LYNK-2018-179*, report submitted to The Nature Conservatory, Juneau, AL.

Rico, M., G. Benito, A.R. Salgueiro, A. Diez-Herrero, and H.G. Pereira (2007), "Reported Tailings Dam Failures: A Review of the European Incidents in the Worldwide Context", *Journal of Hazardous Materials*, Elsevier B.V., Vol. 152, pp 846-852.

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U.S. Army Corps of Engineers (2019), "Pebble Project EIS, Draft Environmental Impact Statement", https://pebbleprojecteis.com/documents/eis, last accessed 24 June 2019.

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I. M. IDRISS
CONSULTING GEOTECHNICAL ENGINEER
P. O. BOX 32027, SANTA FE, NM 87594-2027
Cell: (505) 231-3111 *e-mail: imidriss@aol.com*

July 1, 2019

To: Bristol Bay Reserve Association

From: I. M. Idriss

Subject: *Review of Selected Portions of the Draft Environmental Impact Statement (DEIS) for the Pebble Mine Complex Related to the Tailings Dam Embankments*

To prepare this Report, I went over a number of documents provided to me by Bristol Bay Reserve Association, consisting of relevant sections of the "Draft Environmental Impact Statement (DEIS)", and other reference documents in the DEIS, prepared by AECOM/Knight Piésold in 2018/2019 on behalf of the United States Army Corps of Engineers for the proposed Pebble Mine Complex (Project). The documents provided include:

- Section 3.15 – Geohazards
- Section K3.15 – Geohazards
- Section 4.15 – Geohazards
- Section K4.15 – Geohazards
- Section 4.27.6 – Tailings Release
- Section 4.27.7 – Untreated Contact Water Release
- Section 4.27.8 – Cumulative Effects
- AECOM, Pebble EIS-Phase Failures Modes and Effects Analysis Workshop Report (December 2018)
- Appendix B – Alternatives Development Process
- Appendix N – Project Description
- Knight Piésold, RE: RFI 008 Response – Embankment Static and Seismic Stability – 2018
- Other subsections and figures related to the tailings dam embankments

Based on my brief review of these documents, I have prepared summary comments regarding:

1. Seismic sources and earthquake ground motions
2. Geologic features that may impact stability and/or seepage
3. Embankments
    a. Foundation soils
    b. Drainage
    c. Embankment zoning/construction
4. Stability – static and seismic
5. Deformation Analyses
6. Additional Observations
7. Closing Remarks

This Report covers, to the extent possible, what is (or is not) included in the documents you sent me, and the adequacy/completeness of the information provided.

1. Seismic Sources and Earthquake Ground Motions

The seismicity of the area needs to be brought up to date and the currently acceptable procedures should be adopted to produce the relevant seismic input parameters. The latter include the calculation of target spectra and appropriate accelerograms that are compatible with the target spectra. These spectra and associated accelerograms are usually obtained for a "rock outcrop" at the site and then used to evaluate the seismic performance of the various facilities at the site.

The use of the peak ground acceleration alone, as suggested in the DEIS, is inappropriate.

The DEIS includes a table designated as "Seismicity – Mine Site" that lists the seismic sources and provides values of peak ground acceleration for a number of earthquake events considered by Knight Piésold in the evaluation of the performance of the embankments during earthquakes.

The distance from the seismic source to the mine site in this table is listed as "epicentral distance", a metric that has not been used in earthquake ground motions models (GMMs) for more than four decades. This raises concern about the adequacy of the GMMs used for calculating the values listed in the table, a copy of which is presented below for ease of reference.

Seismicity – Mine Site

Earthquake Source Type	Earthquake Source Name	Source/Fault Mechanism	Maximum Magnitude (Mw)	Epicentral Distance (miles)	Focal Depth (miles)	Maximum Acceleration	
						Median (g)	Median + 1 S.D. (g)
Interface Subduction	Alaska-Aleutian Megathrust	Thrust	9.2 (9.5)	120	25	0.08	0.14
Intraslab Subduction	Intraslab Event	In-slab	7.5	110	40	0.05	0.11
			8.0	110	40	0.08	0.16
	Deep Intraslab Event	In-slab	7.5	60	80	0.15	0.28
			8.0	60	80	0.28	0.48
Shallow Crustal Fault	Lake Clark Fault (Mapped)	Strike-slip	7.8	22	3	0.12	0.20
		Reverse (Thrust)	7.9	22	3	0.14	0.26
	Lake Clark Fault (Hypothetical Extension)	Strike-slip	7.5	7.5	3	0.28	0.44
		Reverse (Thrust)	7.8	7.5	3	0.27	0.46
	Castle Moutain Fault	Strike-slip	7.3	174	3	<0.01	0.01
	Bruin Bay Fault	Reverse (Thrust)	8.0	80	3	0.07	0.12
	Border Ranges Fault	Strike-slip	8.0	130	3	0.02	0.04
	Kodiak Island / Narrow Cape Faults	Strike-slip	7.5	180	3	<0.01	0.01
	Telaquana Fault	Strike-slip	7.0	40	3	0.06	0.09
	Mulchatna Fault	Strike-slip	6.5	65	3	0.03	0.05
	Denali Fault	Strike-slip	8.0	125	3	0.03	0.06
	Maximum Background Earthquake	Strike-slip	6.5	< 1	7.5	0.31	0.56
		Reverse (Thrust)	6.5	< 1	7.5	0.36	0.61

Table reproduced from the DEIS.

2. Geologic Features that May Impact Stability and/or Seepage

The portions of the DEIS that cover geologic features that could impact the integrity of the tailings embankments and other Project infrastructure are inadequate to support a conclusion that instability is not an issue or that seepage, enhanced by such features, has been adequately addressed. The DEIS needs to expand the geologic features analysis and discussion to show that those features will not lead to instability or seepage that threatens the Project infrastructure.

3. Embankments

There will be a number of embankments constructed as part of this Project, including those needed to contain the bulk tailings and those to contain pyritic tailings. Portions of these embankments will be supported on "rock" and portions will be supported on "soils" after removing portions of the existing soils prior to construction of the embankment. It is not clear what criteria will be used for the latter.

The embankments cross sections I found in the portions of the DEIS I reviewed are more of a "cartoon" rather than a useful engineering cross section that depicts the various zones of the embankment (core, shell, filter and drainage layers) and underlying foundation layers (soil layers, rock). The maximum section of the bulk tailings storage facility (TSF) is included in the DEIS and is shown below to illustrate the inadequacy/incompleteness of the information provided for review.

Far more details are required, including extent (depth and width) and material properties, for each embankment zone and for each foundation soil layer. In addition, the key properties of the underlaying rock units need to be provided and analyzed in the DEIS.

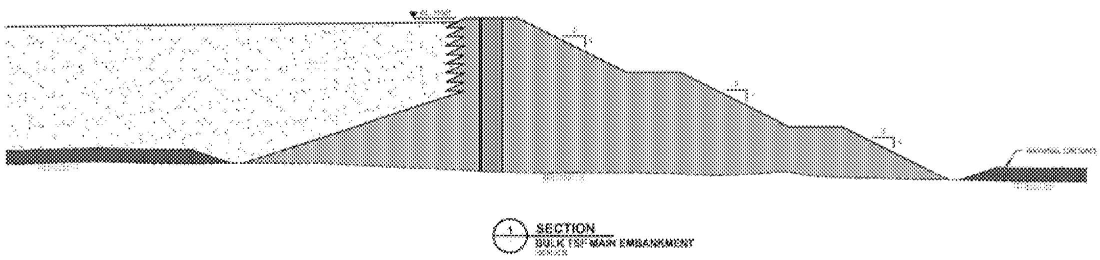

Figure reproduced from the DEIS.

The "Christmas-tree" upstream zone of the section of the bulk TSF embankment, shown in the figure above, requires unique details to be successful, such as: (i) adequate beach; (ii) upstream filters; (iii) minimum width and compaction of the upstream shell and of the filters; (iv) minimum width of core; and (v) appropriate geochemical/geotechnical characteristics of the core materials; etc. None of these details are included in the DEIS.

There are a number of instances in which the DEIS states that various zones will be constructed (e.g., filters, core, etc.) and properly controlled. However, important details and cross sections needed to explain the construction and functioning parts of the dam are not included in the DEIS. Additional information and details of the construction are required to clarify what is being considered, how the proposed controls will be implemented, and how they will function safely during mining operations.

The most unusual item in the DEIS is the statement in Section 4.15 (page 4.15-5) that "(a static FoS of 1.1 or greater is considered stable) *[sic]*"; FoS being factor of safety. I am not aware of that criterion ever being acceptable in any project I ever worked on. The DEIS provides no justification for how would such a minimum FoS be acceptable on this Project.

In my opinion, the information and analyses included in the DEIS regarding TSF embankment design and function are not sufficient to judge the adequacy or acceptability of the proposed design.

4. Stability

The DEIS discusses the static stability for selected sections of the embankments, but provides no information about the zoning, material description, or material properties that are needed to assess the adequacy of the information included in the DEIS.

The use of the so-called "pseudo-static" approach to assess the seismic stability of a slope is inadequate, particularly using the acceleration values listed in the table above to represent the driving force affecting the slope. I could find no explicit statement, in the portions of DEIS I reviewed, that defines where these acceleration values apply.

Normally, a seismic hazard evaluation results in developing target spectra and associated accelerograms to be considered as the rock outcrop motions at the site. The forces applied to the facility (e.g., the TSF embankment section) is calculated using appropriate dynamic analysis procedures. Occasionally it is acceptable in preliminary analyses to use "applicable" simplified procedures to estimate these forces. It is not clear what was done in the DEIS.

Liquefaction of the tailings also needs to be considered in assessing the seismic stability of the TSF embankments. I found nothing explicit about this issue in the DEIS.

5. Deformations Analyses

The approach used in the DEIS is not applicable to the embankments at this site.

Once an appropriate seismic hazard evaluation has been completed for this site and the target spectra and associated accelerograms have been adequately established, a proper nonlinear dynamic analysis, incorporating up to date constitutive models for each zone of the embankments and the foundation layers, can be used to estimate the deformations and deformation patterns of each embankment section. The DEIS needs to include this evaluation and its results. Without it, the DEIS lacks sufficient information from a geotechnical engineering perspective to make a sound judgement about the adequacy of the embankment design.

6. Additional Observations

Pyritic TSF: The DEIS states that the impoundment for this TSF will be lined and that drains will be installed below the liners. It is difficult to assume that the construction will be perfect, or even adequate, and that no puncture will occur in the liners. Therefore, it is important to incorporate defensive measures to control the inevitable leakage from the impoundment and to provide means to collect the seepage and direct it to where it could be appropriately treated. The DEIS, however, does not include this.

Particular Items of Concern: The DEIS includes four items, in particular, that preclude a proper and sufficient evaluation of the Project's infrastructure, including the tailings dam embankments; these items are:

a. Implying that peak acceleration is sufficient to describe the seismic input;
b. Not specifying the location of the seismic input;
c. Proposing that "a static FoS of 1.1 or greater is considered stable"; and
d. Neglecting to include proper cross sections of any of the embankment-foundation layouts under consideration.

7. Closing Remarks

The DEIS for the Pebble Mine lacks up-to-date and a number of the currently acceptable procedures to obtain: (i) the relevant seismic input parameters; (ii) key geologic features that could impact the integrity of the tailings embankments and other Project infrastructure; (iii) useful engineering cross sections that depict the embankment (core, shell, filter and drainage layers) and underlying foundation layers (soil layers, rock); (iv) appropriate static and seismic analyses of embankment stability; (v) proper assessment of earthquake-induced embankment deformations; and (vi) essential defensive measures to control, collect, and treat inevitable impoundment leakage. In addition, the DEIS is constrained by four factors that preclude a proper and sufficient evaluation of the Project, including the implication that peak acceleration is sufficient to characterize seismic input, lack of location for seismic input, proposal that a minimum static FoS of 1.1 is considered stable, and absence of proper embankment-foundation cross sections.

Sincerely,

I. M. Idriss